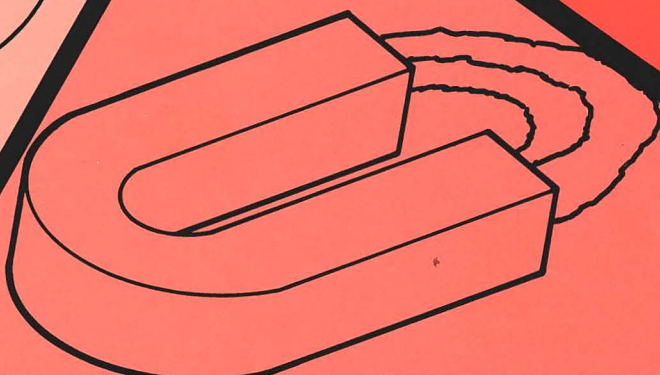
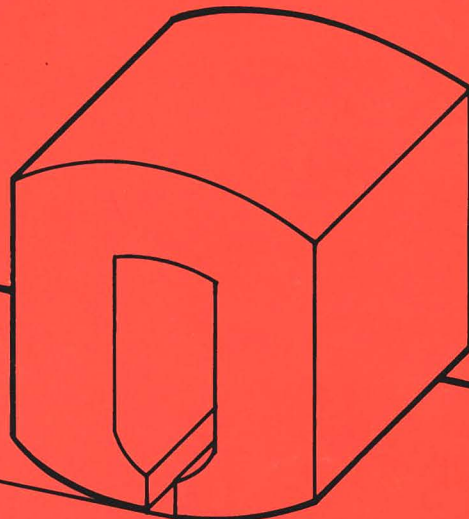
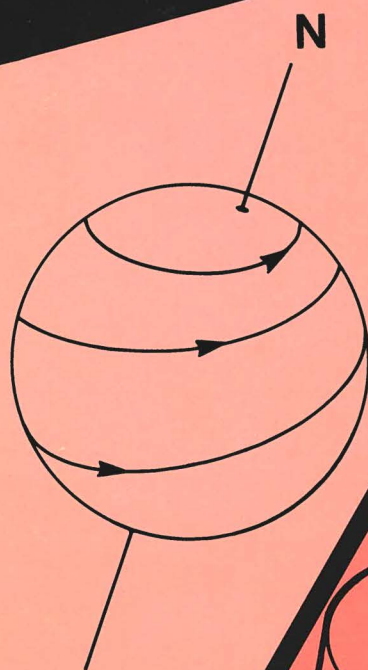


SONY BASIC VIDEO RECORDING COURSE

BOOKLET #1

ELEMENTS OF MAGNETIC RECORDING





SONY®

BASIC VIDEO RECORDING COURSE

BOOKLET 1

ELEMENTS OF MAGNETIC RECORDING

Introduction

Tape recorders make records of analog or digital signals by inducing permanent magnetism into the material of the tape surface. Once magnetized, each tiny area on the tape permits the original signal to be reproduced in the form of magnetically-induced electrical signals.

This booklet reviews some basic concepts of electromagnetism and the units used to measure magnetic properties. As a variation to the traditional approach, this text introduces electromagnetism first and then goes on to permanent magnetism as a special form of electromagnetism due to electrical origins at the atomic level. This subject is extremely complex and some gross simplifications are applied that might not stand up to scientific rigor. However, an attempt at rigorous atomic physics is well beyond the scope of this review.

A word about units. It is unfortunate that two sets of units are in use for the measurement of magnetic properties, and both find their way into current literature applied to VTRs. The older cgs (centimeter-gram-second) values are in common use in such things as tape specifications. For example, intrinsic coercivity for tape is usually given in oersteds, a cgs unit. When magnetic properties find their way into international standards however, a different set of rules apply. Here, mks (meter-kilogram-second) units are used. The two sets of units are not interchangeable and some conversion is required. For the purpose of this booklet, we will start with cgs units and offer conversion tables later in the text.

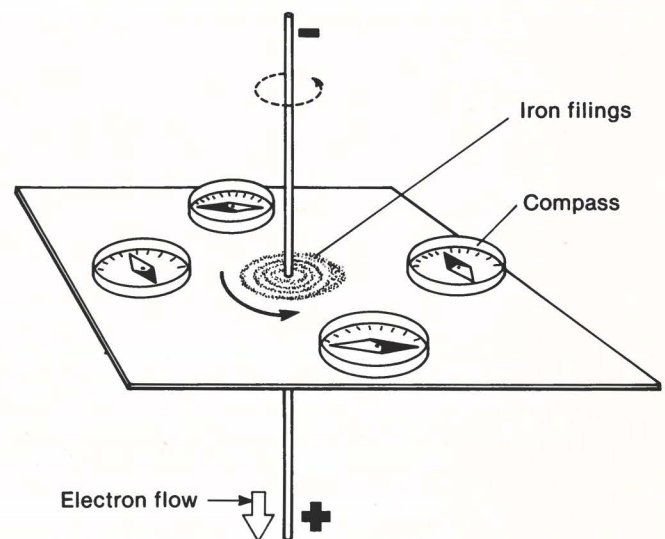


Fig. 1. Magnetic field surrounding a current-carrying conductor.

1. ELECTRO-MAGNETISM

A conductor carrying moving electric charges develops a magnetic field. Its presence can be detected by noting the effect on a compass needle placed near the conductor. If the conductor is passed through a horizontal card, and the card sprinkled with iron filings, the filings tend to link up in circular chains that surround the wire as shown in Fig. 1.

The direction of the field is noted by the force it exerts on the north pole of a compass. As shown in Fig. 1, the compass needle faces in a counterclockwise direction around the wire. This is somewhat difficult to demonstrate

practically, since a current of tens of amperes is needed to overcome the local effects of the Earth's field.

If the conductor is formed into a loop, the resultant field around the loop takes the form shown in Fig. 2. In the center of the loop the force acting on a compass needle is upwards, at right angles to the plane of the loop. The axis of this loop is said to have a magnetic moment. If the loop could be suspended to rotate freely, it would twist so that its axis would settle with the top facing the geographic north pole. The loop has magnetic polarization. The

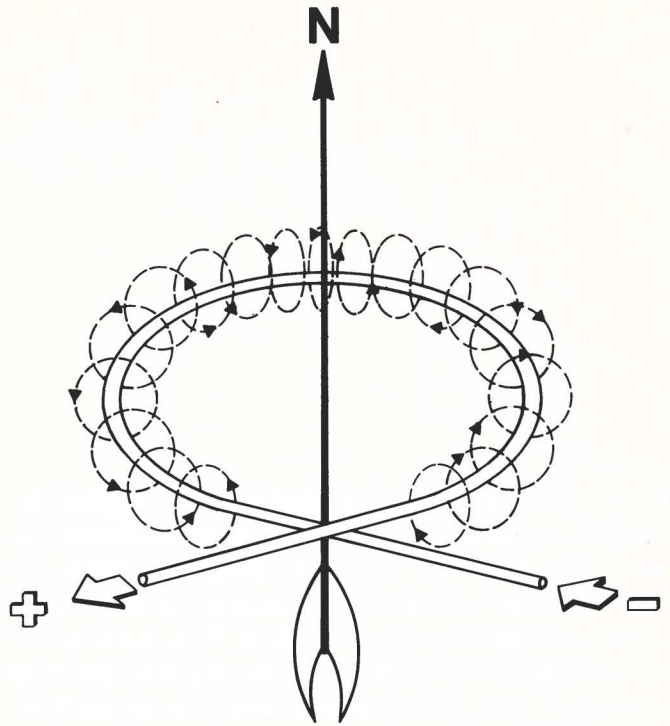


Fig. 2. Current-carrying loop has a magnetic moment aligned with its axis.

top in this case is called, by convention, the north-seeking pole or the north (N) pole for short. The polarization of the loop can be predicted by wrapping the fingers of the left hand around the loops in the direction of electron flow (– to +). The thumb then points to the north pole.

Ferromagnetism. Permanent magnets, like the compass needle itself, behave like the polarized axis of the coil shown in Fig. 2. The origin of this effect is again linked to the motion of the basic unit of electric charge—the electron. If we mentally shrink the circular path shown in the figure to ever smaller dimensions we will eventually arrive at the spinning electron. See Fig. 3. The axis upon which the electron spins is also polarized and has a net magnetic moment. But the forces acting on this tiny magnetic unit are complex. Since all material contains electrons, it is surprising that only a few elements display magnetic properties. However, more elements have magnetic properties than previously supposed. The reason appears to be a cancellation effect in which even numbers of electrons are found to spin in opposite directions.

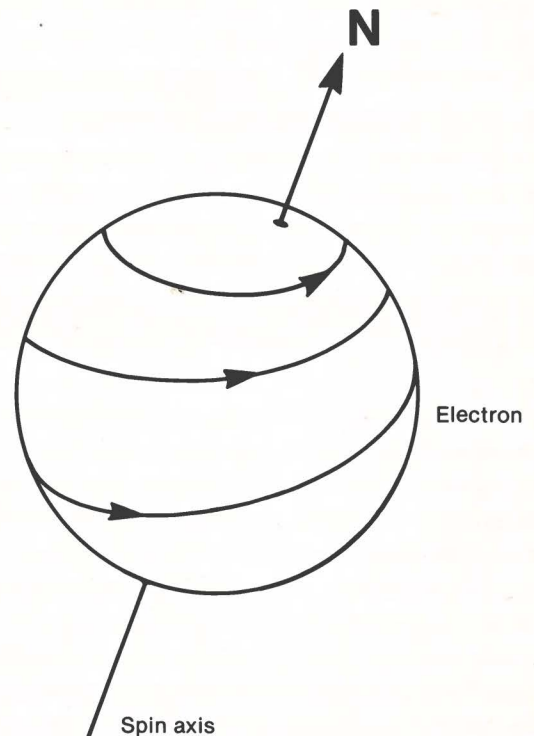


Fig. 3. Electrons have a magnetic moment aligned with the spin axis.

Electrons group themselves in spherical layers, called energy shells, outwards from the nucleus. See Fig. 4. Each shell contains an even number of electrons, except for the outer shell, called the *valence* shell. The number of electrons in the valence shell determines the element's electrical characteristics as well as the way in which it combines with other elements to form stable compounds. The latter always end up with the equivalent of a filled valence shell, and an even number of electrons. Hydrogen having only one electron forms the stable molecular form H_2 in which a pair of atoms share two electrons—each having opposite spins. Thus hydrogen gas has no magnetic properties.

Some of the so-called transitional elements which include iron, nickel and cobalt have unfilled energy shells inside the valence shell. In these shells electrons of opposite spins are not paired off and a net magnetic moment exists.

In the crystalline form of iron, including the ferrite, Fe_2O_3 , and Fe_3O_4 (Magnetite, the original lodestone), the atoms are locked in place in a crystal lattice. However, the magnetic axis can take a number of different directions. Tiny areas in which the crystalline structure is regular, called magnetic domains, act as tiny magnets whose polarity can assume various directions. The crystals are not perfectly uniform however and, taken as a whole, iron or its compounds, behaves as if it were composed of tiny bar magnets which can be made to line up with an external magnetic field of sufficient field intensity.

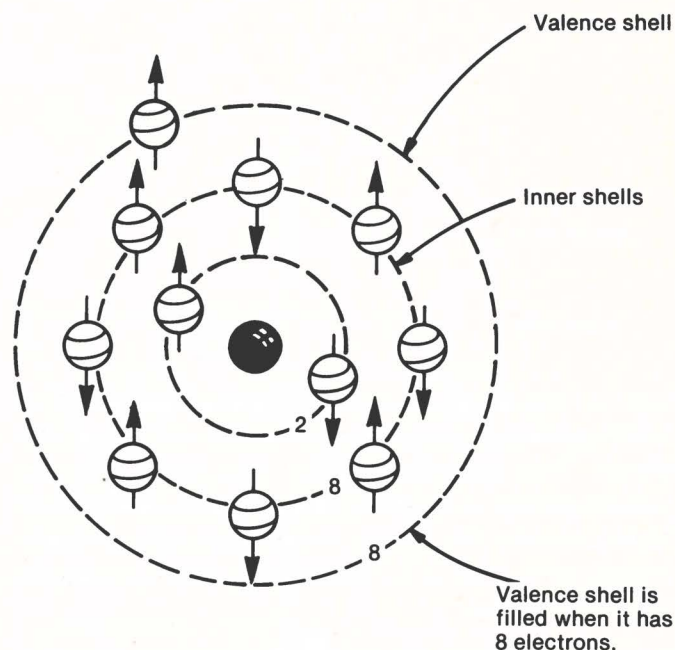


Fig. 4. Sodium atom.

Field Measurements. Let's get back to our coil to explain some basic field measurements. The strength of the field in the coil increases uniformly with current flow. Furthermore, if additional turns are added, as shown in Fig. 5, the fields of each turn reinforce one another so that field strength also varies directly with the number of turns. The quantity NI , where N equals the number of turns and I the current in amperes is known by such terms as magnetizing force and magneto-motive force (mmf). In the cgs system the gilbert is the basic unit for mmf. It is equal to NI times the factor 1.26. The factor is derived from the formula for the surface area of a sphere.

A more practical measurement of field force is field intensity, which takes into account the length of the coil. A shorter coil will produce a more intense field at its center than a longer one. Thus field intensity is measured in terms of mmf per unit length. In the cgs system the basic unit of field intensity is the oersted, which is one gilbert per centimeter. Field intensity is given the symbol H .

Thus
$$H = \frac{NI}{L} \times 1.26$$

Where H is measured in oersteds
 NI = ampere-turns
 L = length of coil in centimeters

Example: Find the field intensity in the center of an air coil consisting of 500 turns, 10 cm in length, carrying 2 amperes.

$$H = \frac{2 \times 500}{10} \times 1.26 = \frac{1000}{10} \times 1.26 = 126 \text{ oersteds}$$

Field intensity is also expressed in terms of the force acting on an imaginary isolated unit north pole. In this expression

$$H = \frac{F}{n}$$

Where H is field intensity in oersteds
 F is the force in dynes
and n is the number of unit poles

Field intensity is a more useful unit than total mmf because it provides a means of indicating field strength at areas removed from the poles. The field intensity of the earth's magnetic field, for example, varies between 0.25 and 0.7 oersteds.

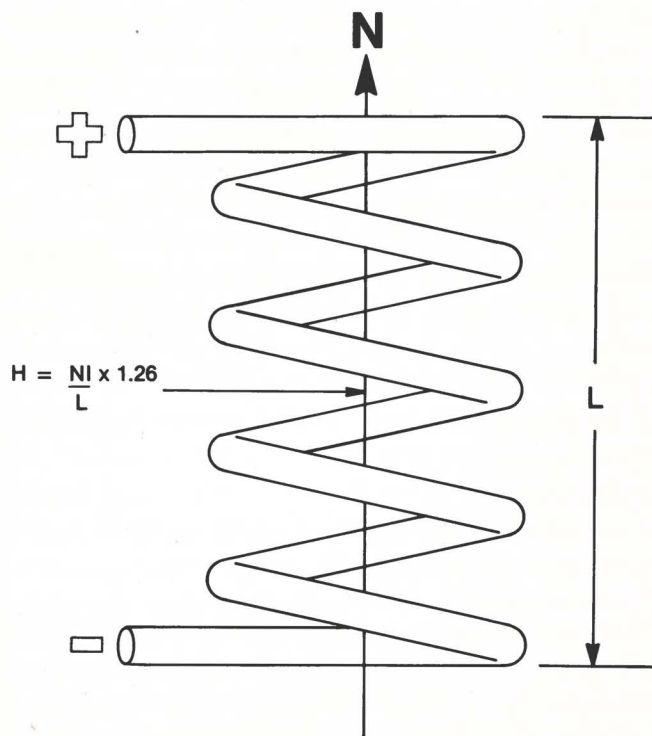


Fig. 5. Field intensity at center of coil depends on current, number of turns and coil length.

Magnetic Flux Lines. The field of force surrounding a coil or a permanent magnet is visualized as lines along which an isolated north pole would be pushed. The idea of an isolated N pole is of course imaginary as the two poles of a magnet can not be separated. This is a purely mathematical concept which makes use of an imaginary unit north pole. Iron fillings sprinkled on a card and placed opposite the end of a coil tend to line up in chains giving a sort of map of these lines of force, called flux lines. The symbol for flux is ϕ and the unit of flux in the cgs system is the maxwell (MX). One maxwell equals one flux line. A large permanent magnet provides a total flux measured in thousands of maxwells.

A more useful measurement of flux is *flux density*, which can relate to measured flux at any point in the field of a magnet. Flux density is given the symbol β and is measured in terms of maxwells (lines) per square centimeter.

$$\text{Thus } \beta = \frac{\phi}{A}$$

Where β is flux density in gauss
 ϕ is total flux in maxwells,
 and A is the area through which
 the field operates in cm^2

Example: Find flux density at the poles of a magnet where total flux is 8000 MX and the pole area is $2 \times 2 \text{ cm}$

$$\beta = \frac{8000 \text{ MX}}{4 \text{ cm}^2} = 2000 \text{ gauss}$$

In the cgs system, flux density and field intensity have the same numerical value in space. Thus, an air-core coil having a field intensity of

50 oersteds has a flux density of 50 gauss in the center of the coil. (The difference between air and vacuum was detected by early physicists but the difference is so small that it can be neglected).

Permeability. When a magnetic substance, like iron, is substituted as the core material the flux that results increases greatly for a given field intensity. The reason is that magnetic domains in the iron align with the coil's field and contribute their own magnetic moment. The flux concentrates in the iron and a much greater flux density is measured there. Flux density is enhanced by the relative permeability (μ) of the core material.

$$\begin{aligned} \text{Thus } \beta &= \mu H \\ \text{or } \mu &= \frac{\beta}{H} \end{aligned}$$

Where β = flux density in gauss
 H = field intensity in oersteds
 μ = relative permeability

In the cgs system, space (air) has a relative permeability of 1. Iron, and its compounds, have permeability values between 100 and 10,000.

Soft iron has a very high value of permeability. If placed in a coil it concentrates the flux inside its borders so that flux density at the poles is determined by the area of the pole faces. When calculating the field intensity of a coil with an iron core, the length of the core, not the coil, is used to calculate H in oersteds. Flux density is considered uniform throughout the length of the core, whereas the formula gives field intensity only at the center of air cores.

TABLE 1
cgs — mks CONVERSIONS

Parameter	Symbol	cgs Unit	→	Multiply by	→	To get mks units
Flux	Φ	maxwells		(1×10^{-8})	=	Flux in webers
Flux Density	β	gauss		(1×10^{-4})	=	Flux Density in teslas
Magneto-Motive Force	mmf	gilberts		(0.7937)	=	MMF in ampere-turns
Field Intensity	H	oersteds		(79.37)	=	Field Intensity in ampere-turns per meter
Permeability	μ	dimensionless number		(1.26×10^{-6})	=	Permeability in T/Nl/m

MKS Units. International standards, such as those produced by the International Electrotechnical Commission (IEC) make use of meter kilogram-second (mks) units. SMPTE standards follow the same procedure. For this reason, standards developed for video-tape recorders include magnetic values in mks units. For example, a reference level for flux per unit track width for audio recordings is expressed in nanowebers per meter.

The mks units are large. For example the unit for flux is the weber which equals 1×10^8 maxwells in the cgs system. For this reason, when dealing with the values used for tape recorder standards flux is expressed in microwebers (10^{-6}) or nanowebers (10^{-9}). Flux density is

measured in teslas. One tesla is one weber per square meter. Magneto-motive force is expressed simply in ampere-turns and field intensity in ampere turns per meter of coil length.

Permeability is somewhat easier to deal with in the cgs system because the definition of B and H values result in space or air having a value of 1. In the mks system however relative permeability must be multiplied by the factor $4\pi \times 10^{-7}$ (1.26×10^{-6}) to obtain absolute values in terms of teslas/ampere-turn per meter. To find absolute permeability in the mks system, relative permeability is multiplied by the factor 1.26×10^{-6} .

Table 1 gives approximate conversion factors to convert from cgs to mks units.

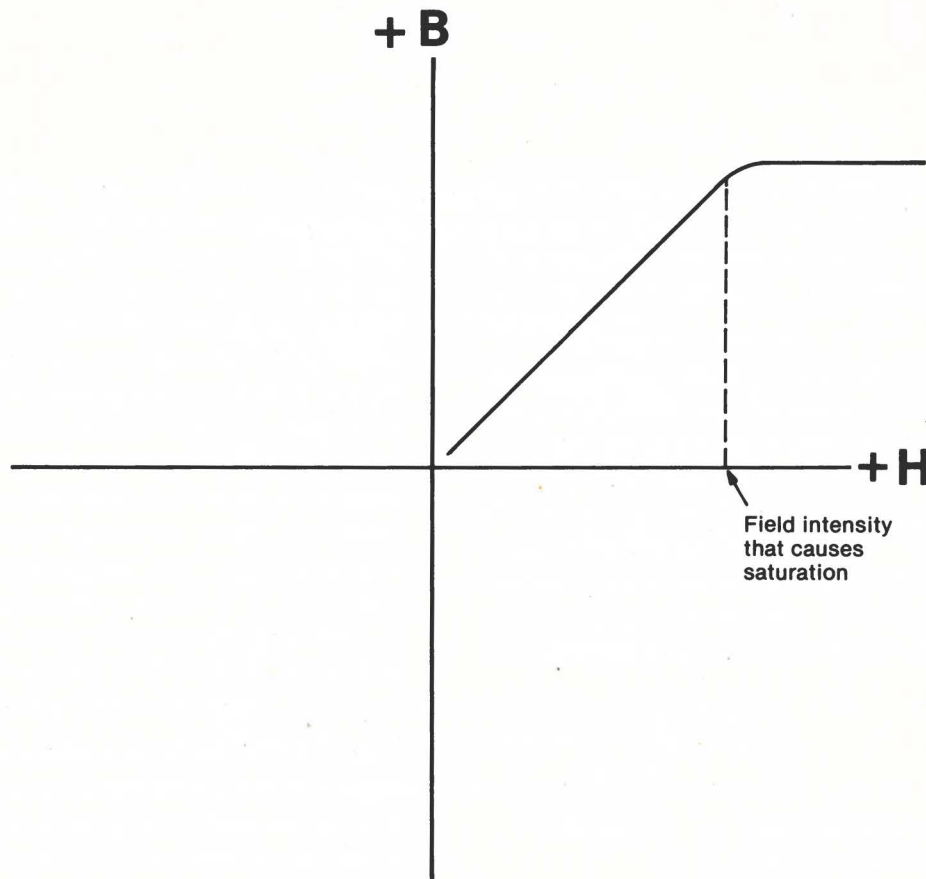


Fig. 6.

2. REMANENT MAGNETISM

In tape recording the prime factor is induced flux in the tape surface and the amount of flux that remains after the recording field intensity is removed. To get a picture of this process we need to understand the relation between flux density and applied field intensity, also how much flux remains after the field drops to zero.

B-H Magnetization Curve. If a graph of applied field intensity (H) versus resulting flux density (B) is made, it becomes apparent that permeability (μ) does not remain uniform. Figure 6

shows such a plot for a soft iron core.

As field intensity rises, flux density rises at a uniform rate showing that permeability is a constant factor. At higher values of H, however the curve is seen to flatten out. This means that increases in field intensity do not result in a corresponding increase in flux density. This condition is known as magnetic *saturation*. It occurs when practically all the magnetic domains in the core have swung into line with the field and there are no more to contribute to an overall increase in flux density.

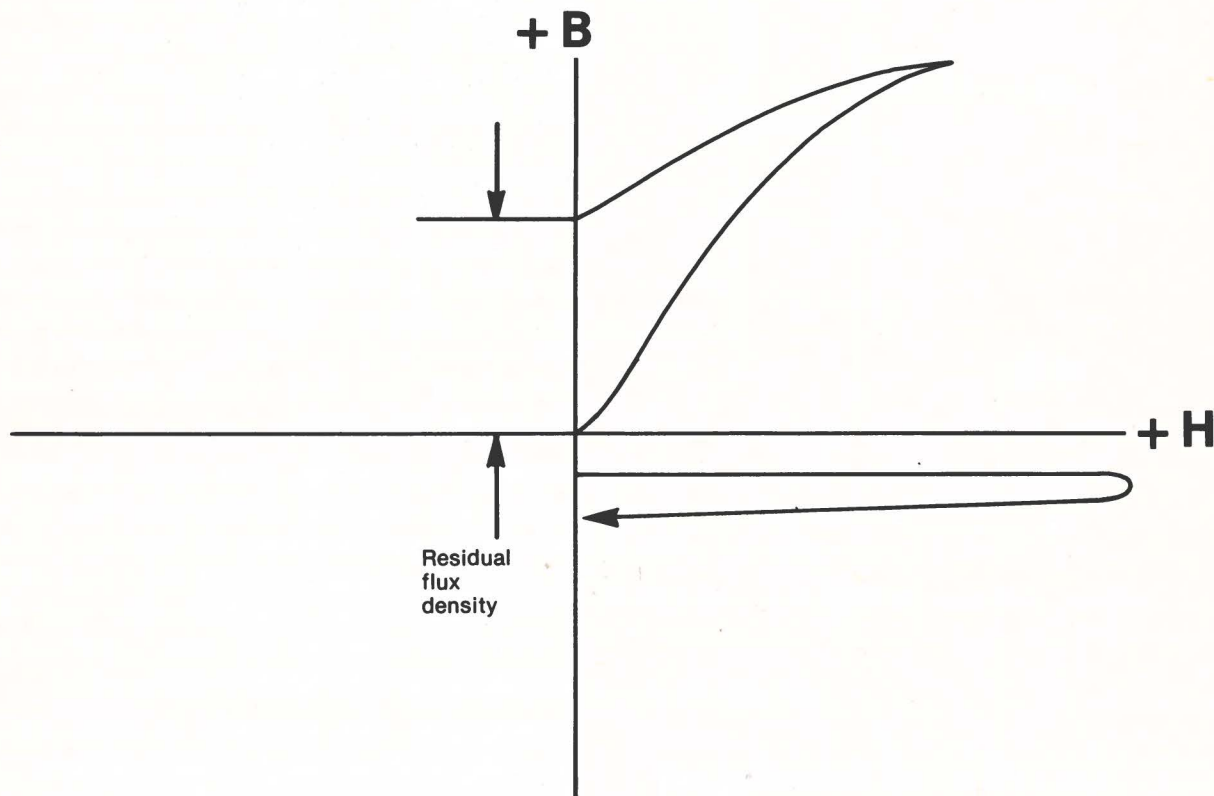


Fig. 7. Magnetization is in the form of residual flux density after H has been reduced to zero.

Remanent Magnetism. When iron or steel is subjected to an applied magnetic field, flux density varies with field intensity, as was shown in Fig. 6. If the field is removed however, flux density does not fall to zero but some residual flux remains. The reason is that the domains do not act as though suspension is fully elastic. That is, they do not resume original orientations after the magnetizing field has been removed. The overall effect of those that remain aligned with the magnetizing

field is a net residual flux. See Fig. 7.

Not all magnetic materials behave the same way in terms of residual flux. Soft iron retains very little; hardened steel retains more and is more suitable for use as permanent magnets. Certain alloys, mostly notably Alnico (aluminum, nickel and cobalt) require more field intensity to produce a given flux but retain a very large percentage of that flux after the field is removed.

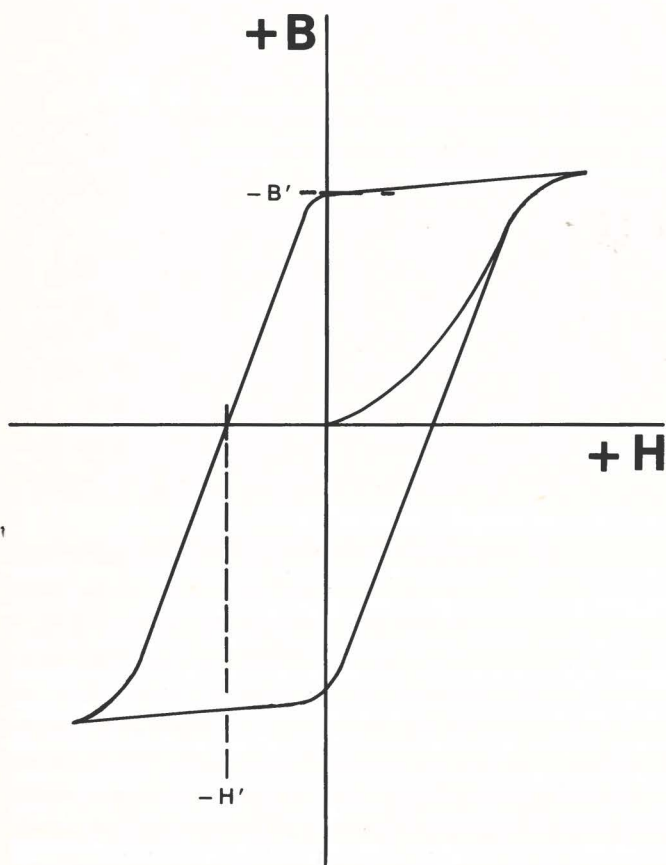


Fig. 8. Closed hysteresis loop formed by reversal of magnetizing field.

A B-H curve plotted for a magnetic material that retains flux forms a closed loop. See Fig. 8. As field intensity rises in the positive direction, flux density follows as shown, until saturation is reached. If field intensity is then reduced to zero, flux density does not fall to zero but drops to the value B' as shown. This is the remanent flux density. To reduce flux density to zero, it is necessary to reverse the field (reverse coil current). At $-H'$ the flux has been reduced to zero. The field intensity required to bring about this condition is called the *coercive force*. A further increase in negative field intensity results in saturation of the opposite polarity. If coil current continues to reverse at the same amplitude, the loop remains closed. Magnetic materials that retain a high percentage of remanent flux produce B-H loops that are rectangular in shape. The loop is called a *hysteresis* loop from a Greek word meaning to be late or fall short.

Intrinsic Coercivity. For tape-recording purposes the material chosen as the recording medium should have a high degree of retention. In addition, it should reach high flux densities before saturation. The remanent flux that remains then provides a greater playback signal and an improved signal-to-noise ratio.

Reluctance. The opposite of permeability is reluctance (R), which in closed paths for magnetic flux is somewhat equivalent to resistance in electrical terms. In this case iron, which has high permeability, is said to have low reluctance. Air, plastic, and other non magnetic materials, have high reluctance. Reluctance is related to magnetomotive force and total flux as follows:

$$R = \text{mmf} = \frac{\text{magnetizing force}}{\text{total flux}}$$

Where mmf is gilberts (or ampere-turns x 1.26)

ϕ is flux in maxwells.

There are no units for reluctance. It is expressed in gilberts per maxwell in the cgs system or ampere turns per-meter per-weber in mks units.

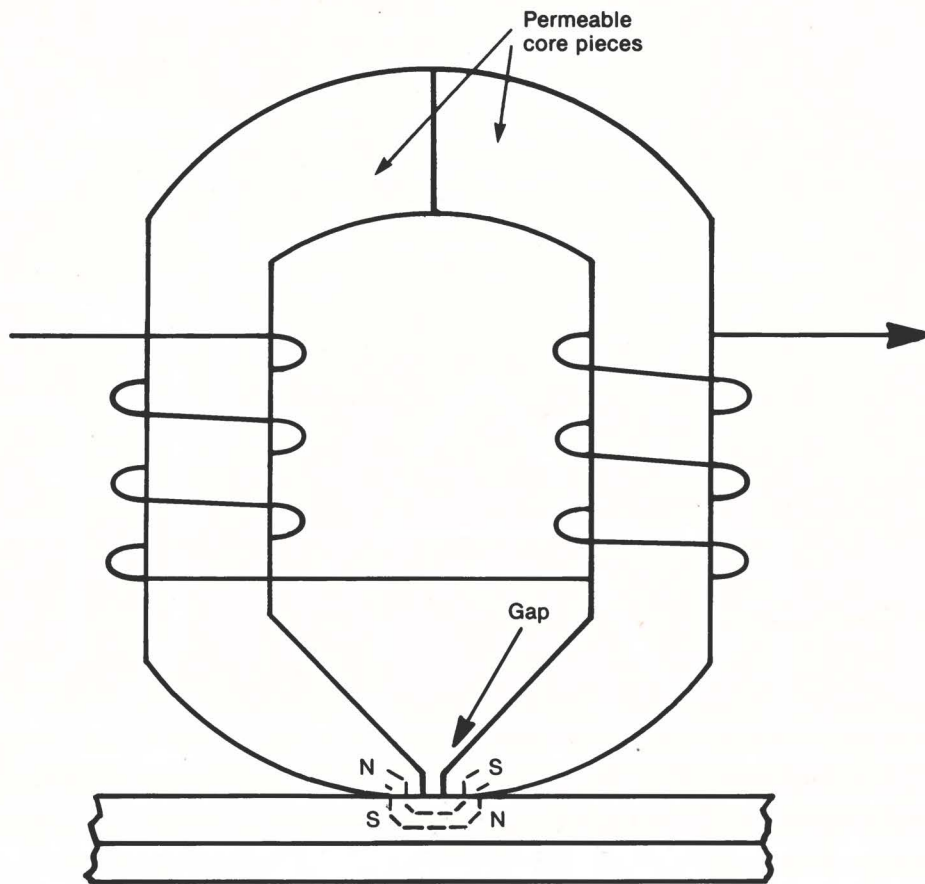


Fig. 9. Basic structure of recording head.

Magnetic Recording Heads. To provide maximum field intensity at the point where the tape surface is to be magnetized, the core of a tape-recorder head is shaped like a closed loop of highly permeable (low-reluctance) material. See Fig. 9. A small gap in the closed magnetic path raises the total reluctance considerably. However, when tape bears against the gap a low reluctance path is provided by the highly permeable material bound to the tape surface. Furthermore the poles of the core pieces are shaped to concentrate flux in the gap area. Thus the head and tape form a low-reluctance or closed path with very high flux density in the tape surface, for a given magnetizing force in the coil.

The material chosen for the magnetic core must be highly permeable to keep reluctance at a minimum. In addition, steps must be taken to minimize losses that occur when high-frequency signals are applied to the coil. These result from eddy currents, and hysteresis. *Eddy currents* are circular currents induced into the core material itself. They act as short-circuit loops and energy is dissipated in the core material in the form of heat. The losses tend to rise with frequency because, as you will see, induced voltage also rises with frequency. To minimize eddy-current loss, the core material should be a very poor conductor of electricity. In audio-recorders, the cores are made of a metal called permalloy. It is formed into thin sheets

that are insulated from one another by a thin nonconductive layer. Video recorders, as well as some audio-recorders make use of ferrite core pieces. Ferrite is a crystalline substance with few free electrons and is a very poor conductor of electricity. Ferrite cores are made by various processes including hot pressed powder or in monocrystalline form. In the latter state the material is grown in the form of single crystals much in the same way as semiconductor crystals are grown. Monocrystalline ferrite is a very poor conductor and therefore has negligible eddy current loss. It is also extremely hard (and brittle).

Hysteresis loss is a complex phenomenon involving energy transfer at the atomic and subatomic level. It is caused in part by thermal losses due to shock waves set up at domain boundaries due to changes in atomic dimensions caused by electron-spin interactions. A crude model depicting hysteresis loss can be

visualized in the form of a spring damped in heavy oil, the spring representing the elastic action of domain direction and the oil the thermal or frictional losses overcome in altering domain directions. At very low frequencies little frictional loss occurs but as magnetizing current changes rapidly, frictional losses rise. In this way hysteresis loss can be seen to rise with the frequency of the magnetizing field. Hysteresis loss is minimized by careful selection of the core material, control of crystal formation, and the shape and orientation of crystals.

The core is usually made of two pieces, as shown in Fig. 9. A tight fit is made opposite the gap, at the rear end of the assembly to minimize reluctance at that point. The gap is made of some non magnetic material whose thickness can be controlled accurately. In video heads the gap is formed of silicon dioxide (glass) and deposited using processes similar to those found in integrated-circuit fabrication.

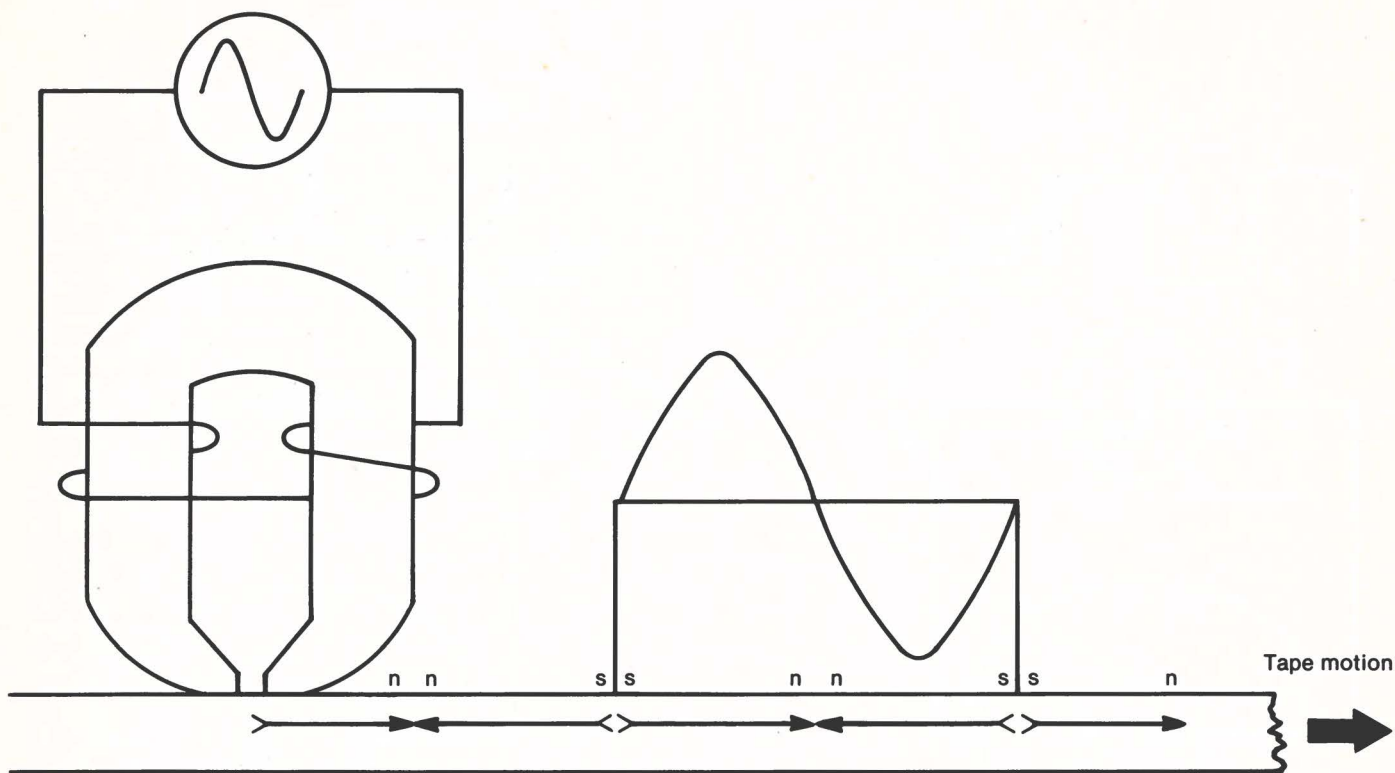


Fig. 10. Flux field reverses with signal current.

Recording and Playback. As tape is pulled past the head the space opposite the gap is magnetized leaving a trail of remanent flux that varies with the current flowing in the coil and reverses polarity (pointing up stream or down) when coil current reverses. See Fig. 10.

To reclaim the original signal, the tape is re-wound and the recorded track pulled past the head. Now as magnetized areas pass the gap, the flux in the tape surface finds the path of least reluctance through the core. Flux expanding and contracting in the core, in proportion to the remanent flux across the gap, induces the output signal. But there is more to it than the flux across the gap at any given moment. Flux must be changing, either rising or falling, for voltage to be induced in the head winding. If tape is stopped at a point on the tape where

remanent flux is high, coil output will drop to zero.

There are three factors involved in inducing the output signal: (1) the amount of flux lines that cut across each conductor of the coil; (2) the number of turns in the coil; and (3) the rate-of-change of flux. Induced voltage can be calculated by Faraday's law, which states:

$$\text{Induced } e = N \frac{d\phi}{dt} \times 10^{-8}$$

Where N = number of turns
 ϕ = flux in maxwells
 t = time in seconds

The lower-case d refers to the calculus term derivative. It is the rate-of-change measured or calculated at any given instant.

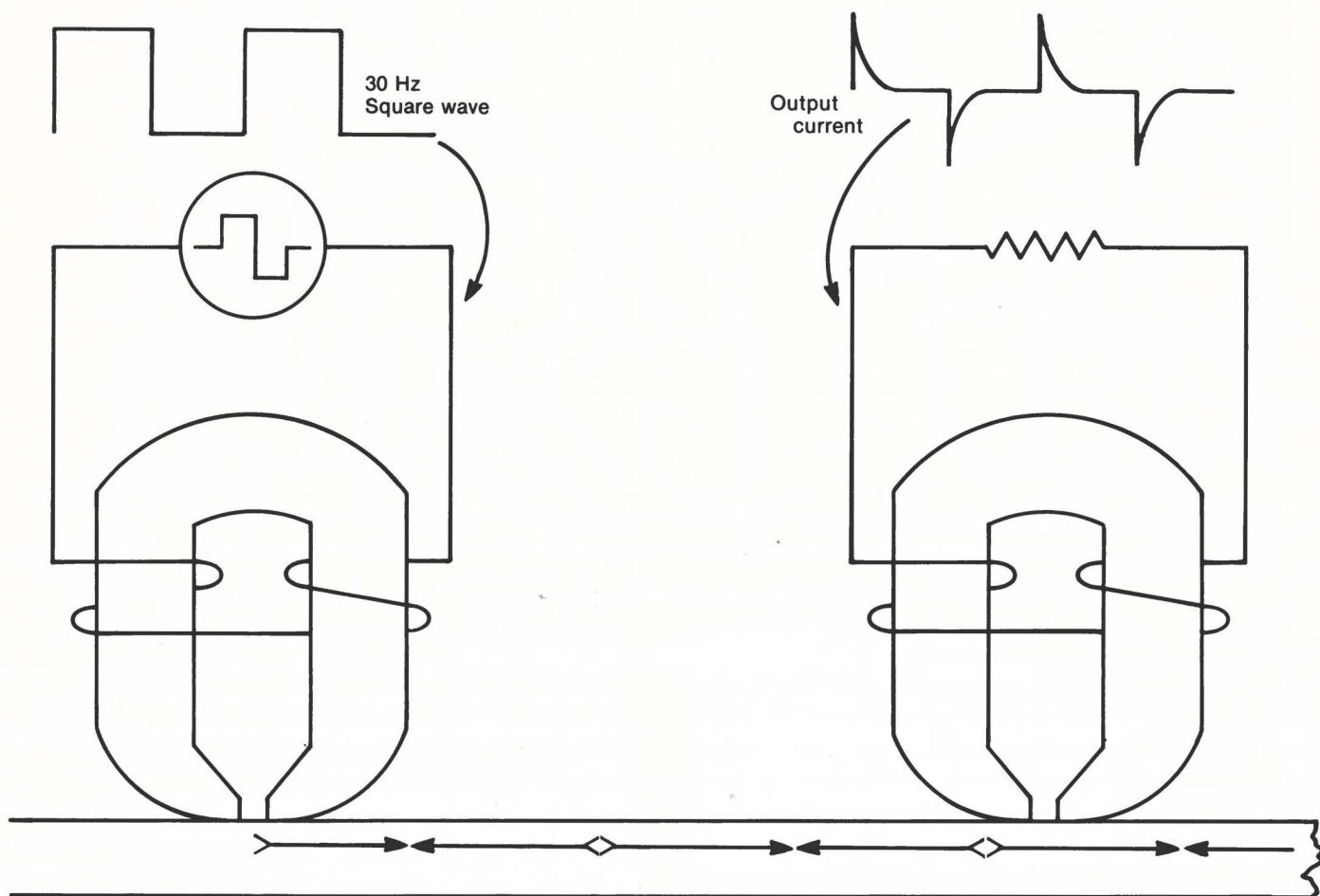


Fig. 11. Output voltage is induced only when flux across the head-gap is changing.

A practical illustration of the effect of flux rate-of-change, can be seen by monitoring the playback voltage produced by the control-track head of a helical-scan VTR. The signal recorded on tape is a 30 Hz square wave as shown in Fig. 11. During the positive half cycle recorded magnetic flux is uniform and points in one direction with respect to tape motion. For the next half cycle recorded flux is equal in maxwells but

points in the opposite direction. When the tape is played back the output waveform looks like a severely differentiated square wave, a series of positive and negative spikes as shown. The reason is that flux in the core changes only when the gap straddles the point in the tape where flux changes (at the transition where flux also reverses).

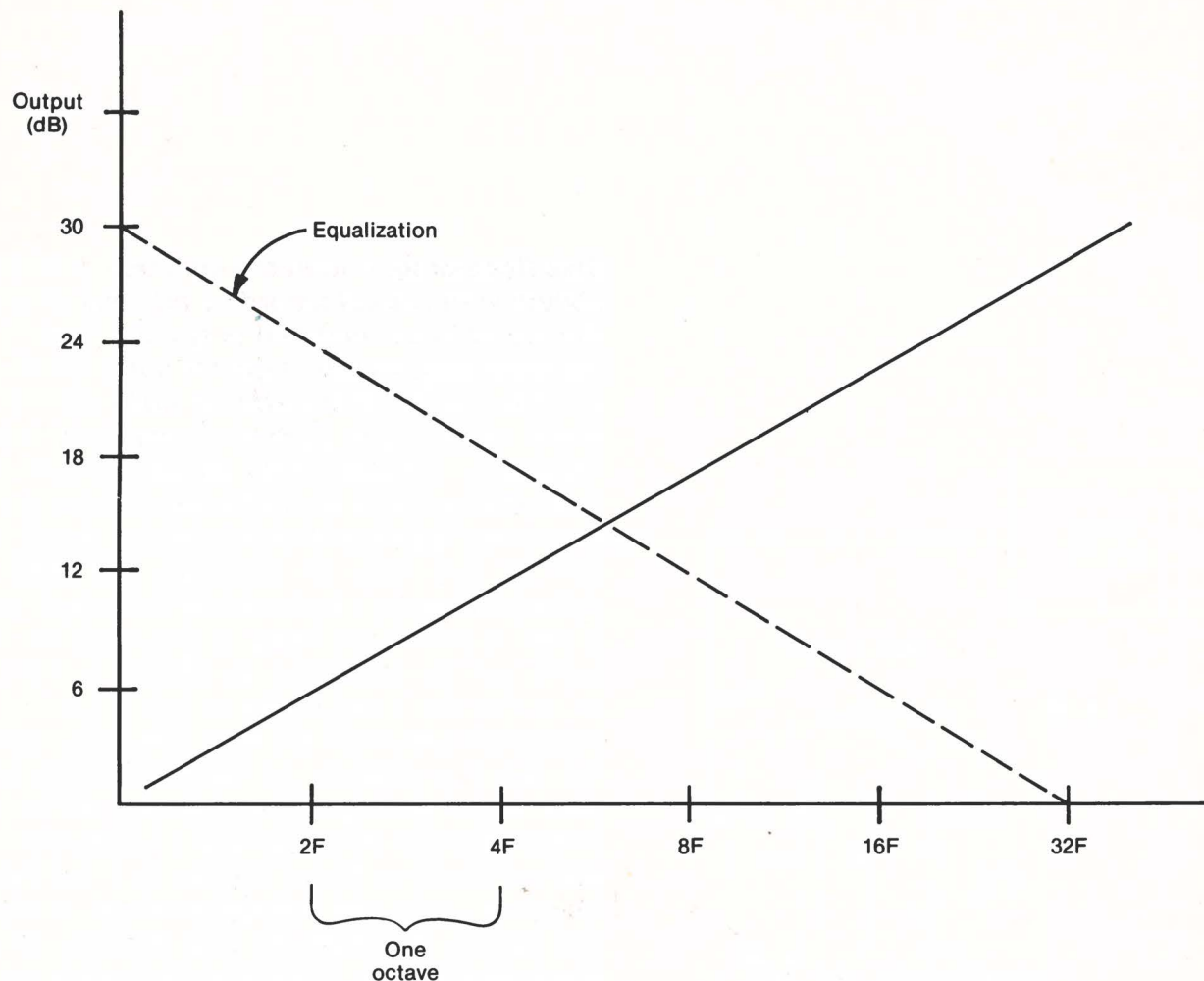


Fig. 12. Playback voltage rises with frequency.

Frequency Response. The rate of flux change in the gap depends upon two factors: the rise time of the recorded signal and the speed with which tape is pulled past the gap. In terms of sine waves the rate of change depends upon the frequency of the recorded signal. As frequency is raised more cycles are crowded in any given length of tape. For this reason output voltage tends to rise steadily as the frequency of the signal recorded on tape rises. Thus a plot of playback frequency response, where signals were recorded at a constant level appears as show in Fig. 12. Playback voltage is zero at zero Hz and rises steadily at the rate of 6 dB per octave in frequency. This plots as a straight line if

frequency is plotted using a logarithmic scale as shown. In this scale each octave is a range over which frequency has doubled. To correct this form of frequency distortion in audio recorders, a playback equalizer provides a bass boost having a characteristic that slopes in the opposite direction. It is important to note, however, that response down to d-c (zero Hz) is impossible. Dc values are important in television recording because the d-c component of the TV signal provides information as to average scene brightness. In later lessons, you will see how the d-c component is retained in video recording.

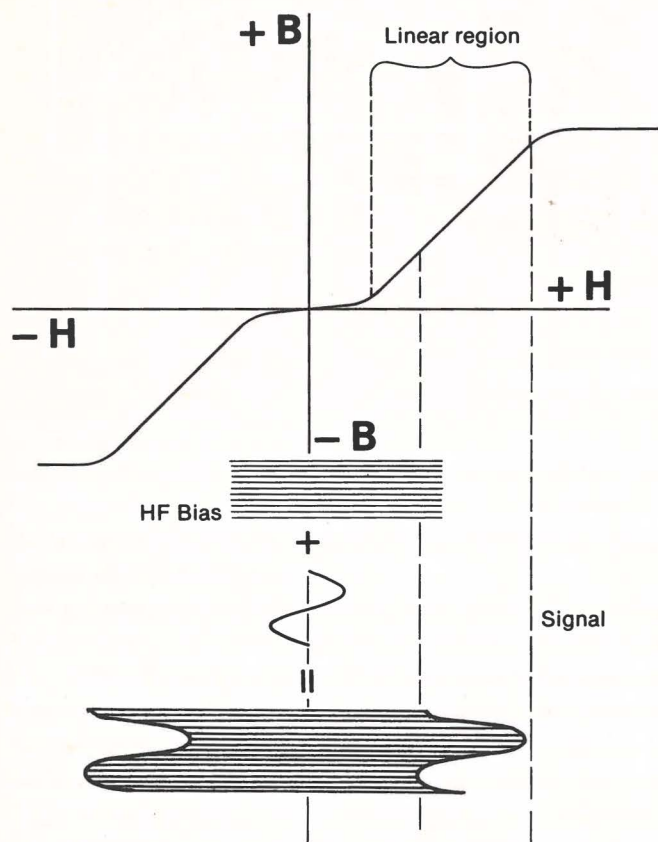


Fig. 13. Use of high-frequency bias to minimize audio distortion.

Bias Recording. A form of amplitude distortion occurs in the *direct recording* process wherein the signal to be recorded is applied directly to the recording heads without the sort of processing that you will study later for video recording. Direct recording is used in conventional audio recorders. The distortion arises because the B-H curve is not linear, but curves at the onset of saturation, and near the origin where field intensity is very low. In practice, the tape is demagnetized by a stationary erase head before it gets to the record head. In that case the B-H curve can be simplified as shown in Fig. 13. Note that the curve hooks at the origin and at saturation and there are only two areas where the curve is straight. To minimize distortion, peak signal excursions should stay within the straight portion of the curve. A d-c bias could be applied, much as bias is applied to a transistor, to center the signal swings on either straight-line portion. However, d-c bias restricts operation to one polarity. It also results in signals produced by mechanical variations in tape movement. For example if the tape should wander so that the track rides back and forth across the head gap, the d-c bias will result in the generation of signal timed to mechanical variations—much like rumble in a turntable.

The solution is the use of an a-c bias signal at a frequency too high to be reproduced. (Limits to high frequency response will be discussed shortly). The bias signal, at 70-90 kHz is simply added to the signal to be recorded. No modulation takes place. Bias level is set so that signal peaks in both polarities stay away from the curved regions in the B-H curve as shown in the figure. The bias signal is essential to minimize distortion, but does not survive the playback process and does not appear in the output signal.

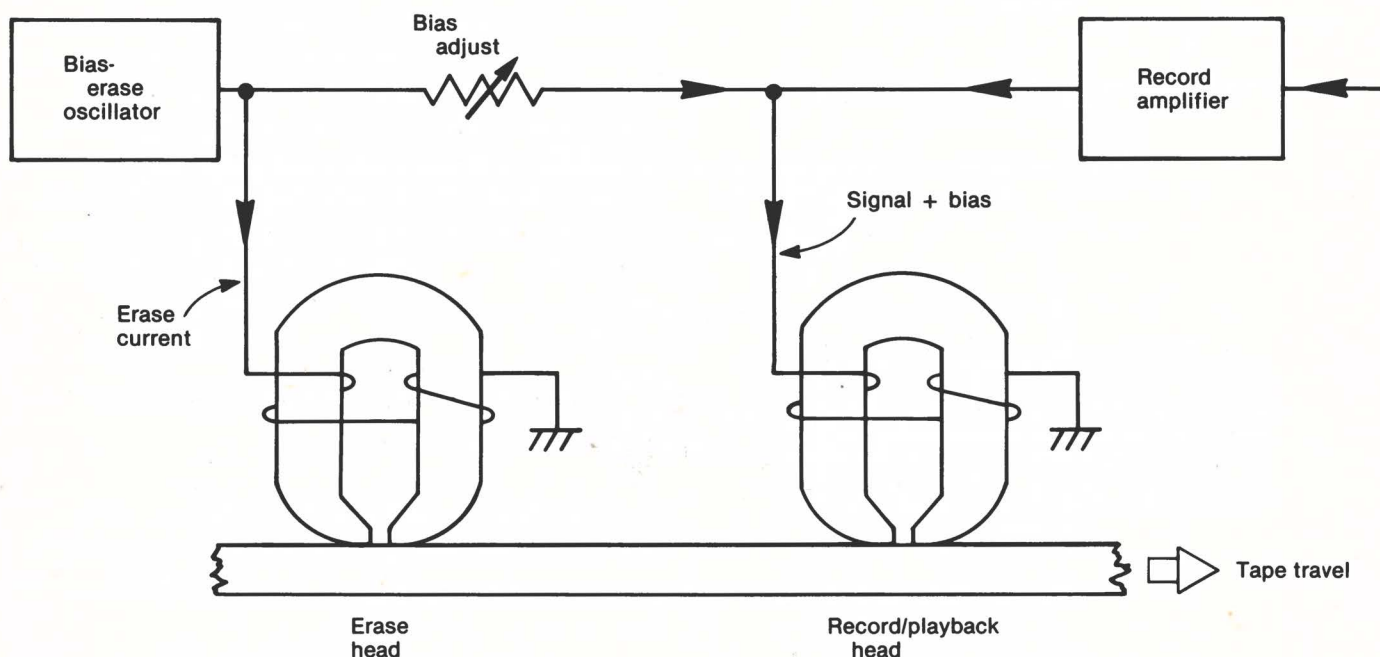


Fig. 14. Erase head precedes record-head along tape path.

Tape Erasure. In tape recorders the tape is pulled past an erase head before it reaches the head where the recording signal is applied. This removes the remanent flux of any previous recordings. The process of erasure is similar to the degaussing techniques applied to color picture tubes and to steel tools to remove unwanted magnetism. The idea is to start out with a strong alternating field and gradually reduce field intensity to zero. Remanent flux then describes smaller and smaller loops on the B-H curve until the origin at zero flux is reached. Ac-

tually, residual flux cannot be reduced to zero in the presence of a static field (the earth's flux field) so that some degree of residual flux always remains. The latter has no practical effect in tape recording. (It is important in color TV however, because the residual field bucks the earth's magnetic field at the location of the steel shadow mask.)

The erase head is driven with a very strong high-frequency signal current. The bias oscillator provides the source for this current. See Fig. 14.

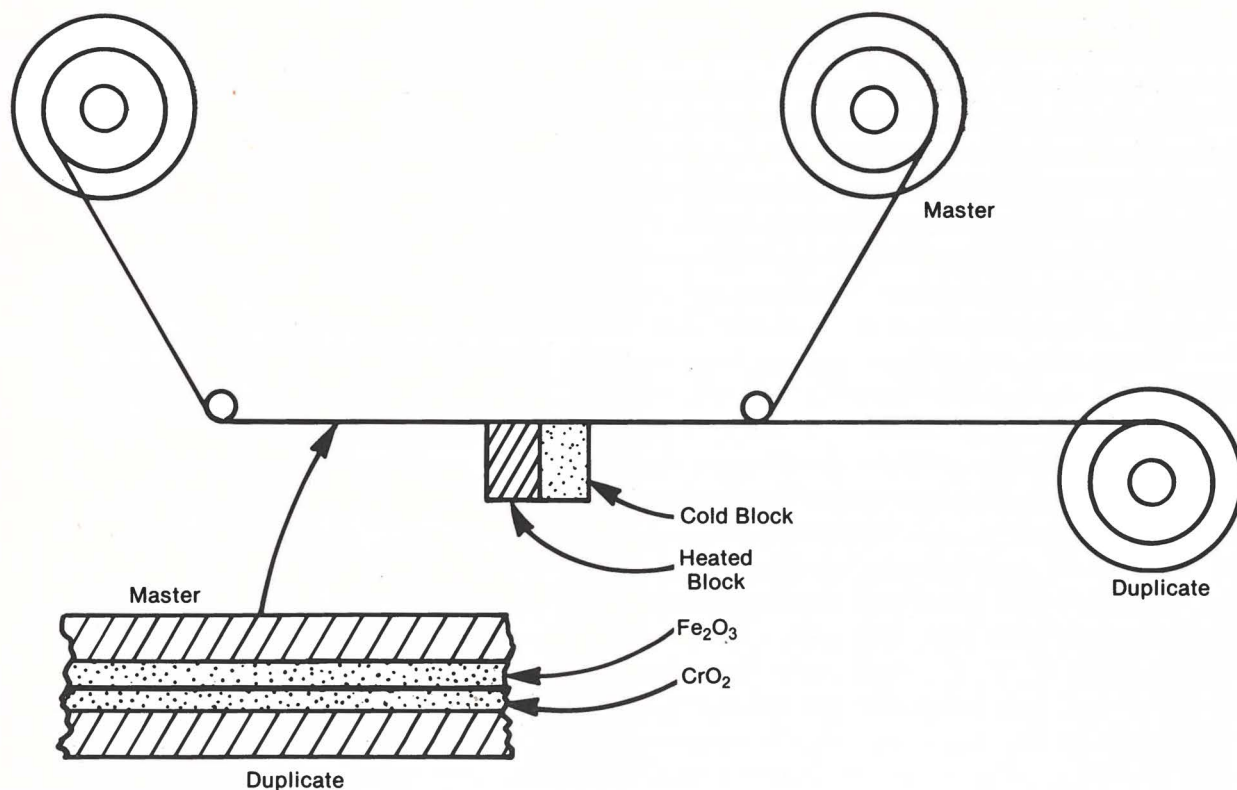


Fig. 15. High-speed duplicator makes use of curie temperature.

Temperature Effects. Before we leave the subject of remanent magnetism and erasure, mention should be made of the *Curie point*. This is a specific temperature at which all residual flux disappears. A specific Curie temperature exists for all magnetic materials and is determined by the level of thermal agitation at which electron-spin interactions are disrupted.

Application of the Curie temperature has been made in thermal high-speed tape duplicators. In this process a mirror-image master tape having a high Curie temperature is wound with a tape having a low Curie temperature. See Fig. 15. The tape pair is then passed over a hot and then a cold block as shown. At the hot block the

temperature is high enough to exceed the Curie point for the blank tape but low enough to avoid erasing the master. When the blank tape cools below the Curie temperature, it is particularly susceptible to domain alignment. Thus, at the cold block, the flux in the master induces flux in the copy.

Although this process is extremely promising as a method for high-speed duplication, there are many practical problems to be solved. These include dimensional changes in the tape and mechanical slippage between the copy and the master. In video copy, these mechanical errors introduce timing errors in the recorded TV signal.

3. HIGH-FREQUENCY LIMITS

Although frequency response rises at the rate of 6 dB per octave, it begins to fall at some point and drops into a deep null. See Fig. 16. The curve begins to level out due to the effects of eddy-current and hysteresis losses at high frequencies. The null however is more basic. It occurs where the flux from the positive and negative halves of the recorded cycle span the head gap as shown in Fig. 17. The oppositely-poled areas act to cancel flux in the gap area. The frequency at which this occurs is when the recorded wavelength equals the gap thickness.

Recorded wavelength in tape recording depends upon the amount of tape pulled past the head in one signal *period*, the time taken for one cycle. As frequency rises for a given tape speed recorded cycles crowd closer and closer together and wavelength decreases. On the other hand, recorded wavelength stretches out if frequency is held constant and tape is pulled past the head at a faster rate.

Thus:

$$\text{recorded wavelength} = \frac{\text{tape speed}}{\text{signal frequency}}$$

For example, recorded wavelength at 15,000 Hz at a tape speed of 19 cm/sec (7.5 inches per second) is

$$\begin{aligned} \Rightarrow \frac{19 \text{ cm}}{15,000} &= .00126 \text{ cm} \\ &= .0126 \text{ mm} = 12.6 \text{ microns} \end{aligned}$$

To obtain maximum frequency response the highest recorded wavelength should be at least twice as long as head-gap thickness. This puts the highest recorded frequencies near the top of the curve shown in Fig. 14. Remember that the null occurs when wavelength equals gap thickness.

One means of extending frequency response is to reduce the gap thickness. The gaps in audio recorders are several microns wide. In the course of VTR development gap thickness has

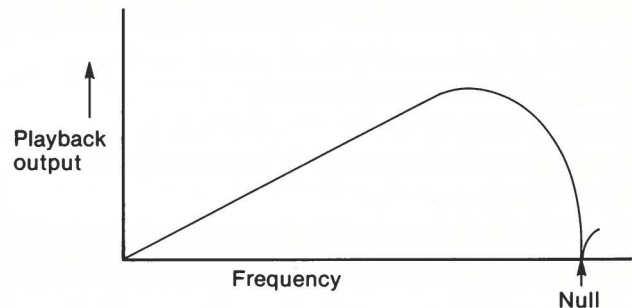


Fig. 16. Output nulls at some frequency due to head-gap effect.

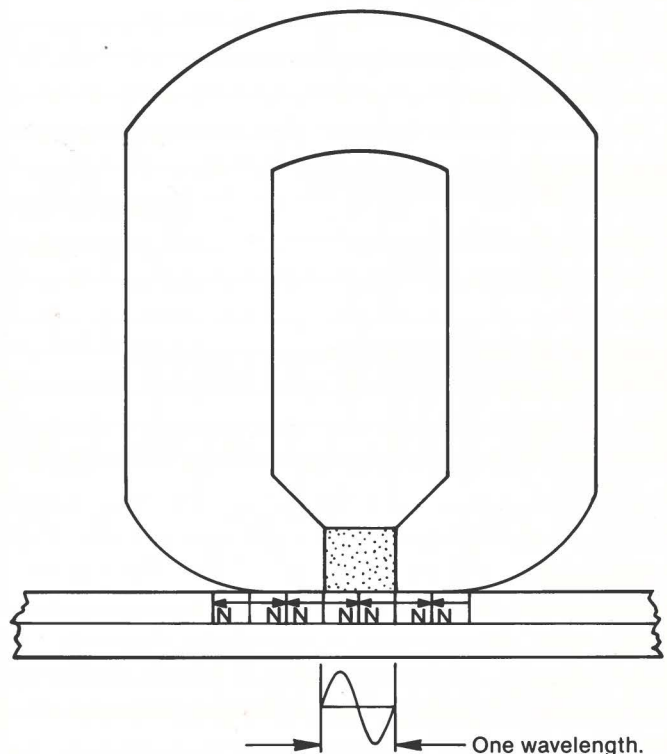


Fig. 17. Output nulls when head gap spans one full cycle of signal flux.

diminished steadily so that video head gaps are measured in tenths of microns (a micron is 10^{-6} meters). However, reduction in gap thickness entails a loss of sensitivity because the reluctance of the gap drops as the poles approach one another: the loss of flux represents a drop in sensitivity.

The remaining variable is tape speed. If tape speed is doubled for a given frequency, wavelength likewise doubles. If you look at the specs for a two-speed tape recorder, you will see that higher frequency response is obtained at the higher tape speed (at a sacrifice in recording time and tape economy).

Consider the tape speed needed if the record/playback head has a gap of 1 micron and the video signal, with a bandwidth extending to 4 MHz, is to be recorded. Recorded wavelength should be at least twice the head gap at 4 MHz or 2 microns. Putting these values into our formula and solving for tape speed:

$$\begin{aligned}\text{record wavelength} &= \frac{\text{tape speed}}{\text{frequency}} \\ \text{tape speed} &= \text{recorded wavelength} \times \text{frequency} \\ &= 2 \times 10^{-6} \times 4 \times 10^6 \text{ Hz} \\ &= 8 \text{ meters per second}\end{aligned}$$

This is approximately 26.4 feet per second. Clearly, if conventional tape transports are to be used tape must travel past the heads at tremendous speeds and tape usage would be staggering. Tape recorders using this high speed approach were built and demonstrated by RCA in 1954. They used 19-inch tape reels that provided only a few minutes of recording time. Modern video recorders employ rotating video heads that cross segments of the tape at high speeds. In these systems the speed of

tape is secondary, but the relative speed between the moving heads and tape is made very high—on the order of tens of feet per second. This relative head-to-tape speed is called *writing speed*.

The methods of increasing writing speed are taken up in the next lesson. It should be pointed out here, that direct recording is not applied to the video signal, as you will see. For this reason the highest frequency to be recorded is somewhat higher than the 4 MHz required for the composite video signal.

Other Tape Losses. In addition to the gap effect, several other factors act to reduce the peak in the playback response curve. Major causes are eddy current and hysteresis loss in the recording medium. The materials chosen have high intrinsic coercivity but they are also very poor conductors of electricity. This is to minimize eddy-current loss. Hysteresis loss is offset by attention to grain size and crystal alignment in the ferrite or chromium dioxide powders.

Another form of high-frequency loss is self erasure wherein neighboring domains act to influence the orientation of immediate neighbors. This effect is also greater at high frequencies where tiny areas of the type are magnetized in opposite directions. The so called high-energy tapes, having higher values of intrinsic coercivity are less susceptible to this form of high-frequency loss.

In the next lesson you will learn how writing speed is raised to the value needed to record the video signal and what special signal processing is used to overcome basic obstacles.

When you have reviewed Video Tape 1 of this series and the material in this text, complete the 20 question self-test at the end of this booklet.

Sony
Basic Video Recording Course
Booklet 1
Glossary of Magnetic Recording Terms

B-H Magnetization Curve—A graphical representation of the resulting magnetization of a material, or flux density (β) as it is affected by an applied magnetic field intensity (H).

Coercive Force—The opposing magnetic intensity that must be applied to a magnetized material to remove (erase) the residual magnetism.

Coercivity—The property of a material determined by the value of the coercive force, when the material has been magnetized to saturation.

Eddy Current—A circular flow of electrons (drift) which occurs within the body of a conductor that is exposed to a rapidly changing magnetic field; the current increases with frequency.

Field, Magnetic: The space around a magnetic particle in which a magnetic force is operative. The operation is such that like poles repel and unlike poles attract.

Field Intensity—Symbolized by H; a measure of the magneto motive force per unit length; the CGS unit is the oersted; $H = NI/L \times 1.26$ (H in oersteds, NI in ampere turns, L in cm).

Flux—Symbolized by ϕ ; The summation of the effects of a magnetic field through an arbitrary space; the CGS unit is the maxwell, or line of force.

Flux Density—Symbolized by β ; a measure of the flux per unit area; the CGS unit is the gauss; $\beta = \phi/A$ (β in gauss, ϕ in maxwells, A in cm^2).

Gauss—The CGS unit for measuring flux density, β .

$1 \text{ gauss} = 1 \text{ weber}/10^{-4}\text{m}^2 = 10^{-4}/1 \text{ maxwells}/\text{m}^2$.

Gilbert—The basic CGS unit for measuring magneto-magnetic force; 1 gilbert = $NI \times 1.26$ (NI = Ampere-turns).

Hysteresis, Magnetic—A lag in the value of magnetization of a magnetic material due to a changing magnetic force. This characteristic occurs between the flux density and the field intensity.

Induction, Magnetic—A physical phenomenon in which two materials interact electromagnetically simply due to proximity. The establishment of a magnetic field in a substance by the proximity of an electrical field, magnetic field or other source.

Intrinsic Coercivity—A property of a material that determines the field intensity at which saturation occurs.

Magneto-Motive Force—mmf; the force of a magnetic field of one mass particle on another mass particle.

Magnetization—Subjecting the magnetic domains of a material to an external magnetic field, inducing a residual flux on the material which is proportional to the applied field intensity.

Magnetic Domains—The intrinsic charge distribution of all matter at the atomic level. The net charge of neutral molecules is zero, implying that charges are divided into balanced pairs or dipoles.

Maxwell—The CGS basic unit for a line of force.

Moment, Magnetic—A force exerted on the magnetic domains of a material at the axis of each magnetic domain or dipole by an external field.

Oersteds—The CGS unit of magnetizing force equal to $1000 \text{ NI}/4\pi\text{L}$.

Permeability—Symbolized by μ ; the ability of a material to align its magnetic domains with an external field, thus contributing its own magnetic moment and increasing the field intensity.

$$\mu = \beta/H \quad (\beta = \text{in gauss; } H \text{ in oersteds})$$

Pole, Magnetic—An area where magnetic flux density concentrates, practically found in pairs or dipoles.

Reluctance—The inverse of permeability. The resistance of a material to align its magnetic domains with an external field. $R = \text{mmf}/\phi$

Remanent Magnetism—When a magnetic material is exposed to a magnetic field, the flux density varies with the applied field intensity. When the field is reduced to zero, some flux due the individual dipole moments of the material will remain. This is the remanent magnetism.

Residual Flux—The flux that remains on a magnetic material due to remanent magnetism.

Retention—The ability of a magnetic material to retain a given residual flux pattern after the originating field has been removed.

Saturation—The point at which all magnetic domains are aligned, in the process of magnetization, when a further increase in field intensity does not result in greater residual flux density.

Tesla—The MKS unit for measuring flux density, β .

$$1 \text{ tesla} = 1 \text{ weber}/\text{m}^2$$

Weber—The MKS unit for measuring flux, ϕ .

$$1 \text{ weber} = 1 \times 10^8 \text{ maxwells}$$

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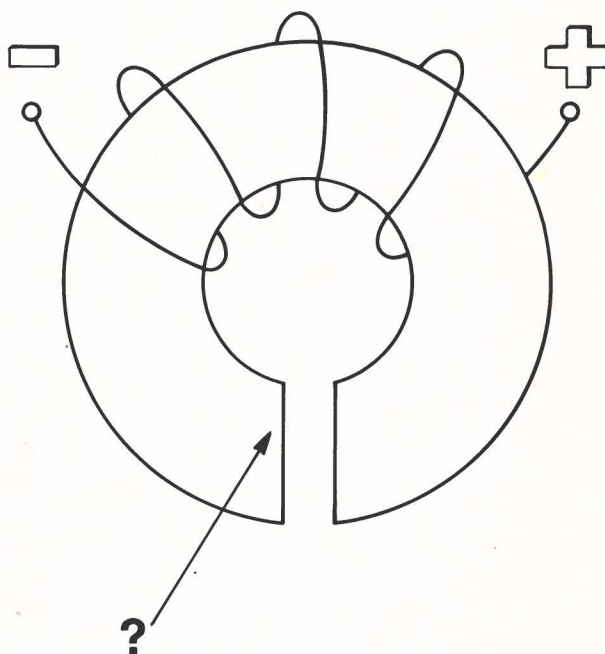
BASIC VIDEO COURSE

BASIC VIDEO RECORDING COURSE

ELEMENTS OF MAGNETIC RECORDING

Circle or fill in your answer.

1. In the cgs system of measurement, flux density is expressed in (a) gauss; (b) webers; (c) oersteds; (d) ampere-turns.
2. In Fig. 1 the left hand pole (at the left side of the gap) is a _____ pole.
3. The field intensity at the center of a coil of 300 turns and 2 cm in length carrying 50 ma is: (a) 7500 gilberts; (b) 750 gauss; (c) 75 oersteds; (d) 7.5 oersteds.
4. The flux density in the center of the coil in question 3 is _____.
5. If an 2 cm iron bar with a permeability of 400 is placed in the coil of question 3, the flux density will be _____ gauss.
6. A bar magnet of circular cross section having a diameter of 1 cm has a total flux of 2000 maxwells. The flux density at the poles is _____ gauss (area = πr^2).
7. A typical value for the permeability of iron is (a) 0.005; (b) 1; (c) 1000; (d) 50,000.
8. A condition whereby flux density stops rising even though applied field intensity continues to rise is called _____.
9. Of the following, the material with the least reluctance is: (a) air; (b) iron; (c) aluminum; (d) copper.
10. Name three factors that result in high-frequency losses in tape playback _____.
11. Between the frequencies of 100 and 400 Hz, which were recorded at constant amplitude, the playback output will change by (a) + 6 dB; (b) - 6 dB; (c) + 12 dB; (d) + 18 dB.
12. To minimize eddy-current loss the material chosen for record head cores is a _____ conductor of electricity.
13. A tape material that saturates at a higher field intensity is said to have a higher intrinsic _____.
14. If a steady signal at 1000 Hz is recorded on tape and played back, first at 7.5 ips, then at 15 ips, the output at the higher speed will be: (a) higher in frequency only; (b) higher in frequency and amplitude; (c) unchanged; (d) higher in frequency but lower in amplitude.



Quiz Fig. 1.

15. If direct current is applied to the recording head: (a) the tape will not be magnetized; (b) flux density at the gap is zero during playback; (c) output voltage will be zero during playback; (d) output voltage will be fixed during playback.
16. High frequency bias is added to the signal to be recorded in audio tape recorders to: (a) increase frequency response; (b) minimize noise; (c) prevent tape saturation; (d) minimize distortion.
17. The first null in playback frequency response occurs at 20,000 Hz with a tape speed of 200 mm per second. The head-gap thickness is _____.
18. To produce a recorded wavelength of 1.2 microns, at 5MHz the writing speed must be: (a) 6 mm per sec.; (b) 600 mm per sec.; (c) 0.6 meters per sec.; (d) 6 meters per sec.
19. Total magnetic flux in the mks system is measured in: (a) gauss; (b) maxwells; (c) webers; (d) teslas.
20. To extend playback frequency response an alternative to increased writing speed is: (a) a reduction in intrinsic coercivity of the tape material; (b) a boost in record current; (c) a reduction in head-gap thickness; (d) an increase in bias frequency.

Answers:

- | | | | |
|--------------|---|-----------------|-------------|
| 1. (a) | 6. 2546.5 | 11. (c) + 12 dB | 16. (d) |
| 2. north | 7. (c) | 12. poor | 17. 0.01 mm |
| 3. (d) | 8. magnetic saturation | 13. coercivity | 18. (d) |
| 4. 7.5 gauss | 9. (b) | 14. (b) | 19. (c) |
| 5. 3000 | 10. eddy current loss;
hysteresis loss;
self erasure;
gap loss | 15. (c) | 20. (c) |

THE UNIVERSITY OF CHICAGO

SONY®

Video Products Company

Published by

VIDEO TECHNICAL INFORMATION

700 WEST ARTESIA BLVD., COMPTON, CA 90220

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